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PRODUCTION OF METAL COMPOSITE MATERIALS

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A low activity of components with respect to each other and a significant difference in their CLTEs presents certain difficulties in the production of metal ceramic composites based on an argillaceous matrix with a high content of metallic filler. The performed studies have made it possible to develop a technology for producing such materials and identify the physicochemical processes responsible for the physicomechanical and service properties of composites.

Extensive implementation of composite materials with metal matrices in construction is currently impeded by the complexity and high cost of their production,. However, there are certain "weak spots" where traditional materials, due to their insufficient strength, impact viscosity, plasticity, heat resistance, etc. are unable to provide the required level of service properties; for instance, airfield coatings for vertical take-off aircraft, floors in metallurgical production shops, storage facilities for radioactive waste, lining of underground structures, etc. [1].

The problem can be solved by lowering the production cost of composite materials, which can be achieved by partly replacing expensive metal by an inexpensive filler. An attempt of creating such materials has led to the development of composite construction materials based on a metal filler and a nonmetal matrix [2].

Metal composites are promising materials for contemporary engineering. They have a number of valuable properties typical of ceramics (hardness, high strength, low creep) and of metals (high thermal conductivity, electric conductivity, and resistance to shock loads).

According to their physical properties (specific weight, CLTE, thermal conductivity, etc.) metal ceramics take mainly an intermediate position between the corresponding ceramics and metals [3]. Metal substantially improves the tensile strength and plasticity of a metal composite, which is needed at high temperatures for suppressing thermal stresses and stresses arising in polymorphic transformations; metal may also has a positive effect on erosion resistance. However, the metal component induces creep in metal ceramics at high temperatures, decreases its refractoriness, increases oxidizability, and contributes to the formation of thermal stresses due to the difference in the CLTEs of the ceramic and metallic phases. The introduction of a metal filler at the state of batch preparation makes it possible to lower its negative effect on the properties of metal ceramic composites.

The development of new cermet composites based on an argillaceous matrix with a high content of aluminum filler is impeded by a low activity of the components (aluminum and the argillaceous components) with respect to each other and a substantial difference in their CLTEs. Therefore, an important challenge in the chemistry and technology of cermet materials is identifying the nature of the bond and the strength of adhesion between the components.

The physicomechanical properties of the obtained materials to a large extent depend on the type of adhesion between the matrix and the filler. Depending on the physicochemical properties of the individual components and the mechanism of formation of bonds on the phase boundary, adhesion interaction can be split into three groups [1]. They are: mechanical adhesion caused by the absence of a chemical interaction and mechanical cohesion formed between the matrix and the filler, physical adhesion related to the interaction between the electrons at the atomic level; and physicochemical adhesion including an irreversible wetting of the matrix with a melted filler, their mutual dissolution, and subsequent formation of chemical compounds and solid solutions.

The clay components in cermet composites is a multicomponent material combining crystalline and amorphous phases, mainly of the oxide type. Therefore, the main specifics of the bond formation in metal ceramic composites is the fact that the bond between the components is controlled by different mechanisms, in contrast to other known composites

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in which the same type of bond exists over the entire interface surface. The materials considered in this study typically form mixed bonds involving mechanical and physicochemical adhesion.

The adhesion between phases in heterogeneous systems depends on the ratio of their surface energies and the value of the surface tension between the phases; it is realized according to the Van der Vaals force acting between the phases and also as a consequence of the formation of intermediate compounds and solid solutions. A study of the interaction between molten metal and nonmetallic materials indicates that wetting is an essential condition for producing strong composites.

For better wettability of metal with the filler, its surface is treated with special additives including solutions of alkali metal salts, mineral and organic acids, calcium, selenium, and chromium hydroxide solutions [4]. The introduction of small quantities of additives chemically reacting with both metal and ceramic perceptibly facilitates the formation of a strong bond between particles of different chemical nature.

In our study to ensure the compatibility of the argillaceous matrix with an aluminum filler and to create a single-phase structure in the composite, we performed a chemical modification of the clay surface using Al^{3+} ions from aqueous solutions. The purpose of modifying the clay component in the development of a cermet composite is to induce the epitaxial growth of an aluminum microlayer on the surface of clay particles, in order to ensure the homogeneity of the argillaceous matrix with the molten aluminum filler. This has made it possible to raise the content of aluminum in the composite to 20% while avoid the defects of fused metal areas or loosening the structure by unstable aluminum interlayers, to lower the temperature of the formation of a liquid phase by 80 – 120°C, and to shift the viscosity curve maxima to a lower temperature range.

Aluminum particles melt during the firing of the composite and behave as a binder, wetting and binding the grains of the argillaceous component. Wetting in a metal composite is accompanied by a chemical reaction between the components (which are phases) and the formation of a new phase, which is a new compound with peculiar properties that are not a sum of the properties of metal and ceramics. The better the wetting, the better the quality of the metal composite produced.

As modified clay mixtures are fired in the presence of the metal filler, physicochemical processes take place that determine the structure and properties of the obtained material.

Part of aluminum in heating becomes oxidized and forms oxides which participates in the formation of the composite structure. A physical adhesion arises between excess aluminum and the modified matrix surface caused by the interaction between the electrons at the atomic level.

Thus, the properties of metal composites are determined by a number of physicochemical processes occurring under heating: wetting of clay particles with molten metal, chemical reaction between the phases, and their mutual dissolution.

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